

Silicon Radiation Damage and Expected Run II Lifetimes

S. Worm
University of New Mexico
~~PRISSES~~

June 14, 2000

FEB 2002

Overview

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- Summary

The relationship between signal-to-noise ratio and b tag efficiency: How long can silicon detectors survive radiation exposure?

J. Albert¹, R. Culbertson², D. Glenzinski³, J. Incandela¹,
E. Kajfasz¹, N.M. Shaw⁴, F. Snider³, D. Stuart¹, M.J. Wang⁵

Abstract

In run 1A (1992-93) there was an apparent correlation between reduced b tag efficiency and increased radiation damage to the CDF dc-coupled silicon detector (SVX). We use the Monte Carlo (MC) simulation created for the new CDF ac-coupled detector (SVX') to study this correlation. This is accomplished by scaling the signal size and adding noise and pedestal shifts in the MC to match the operating

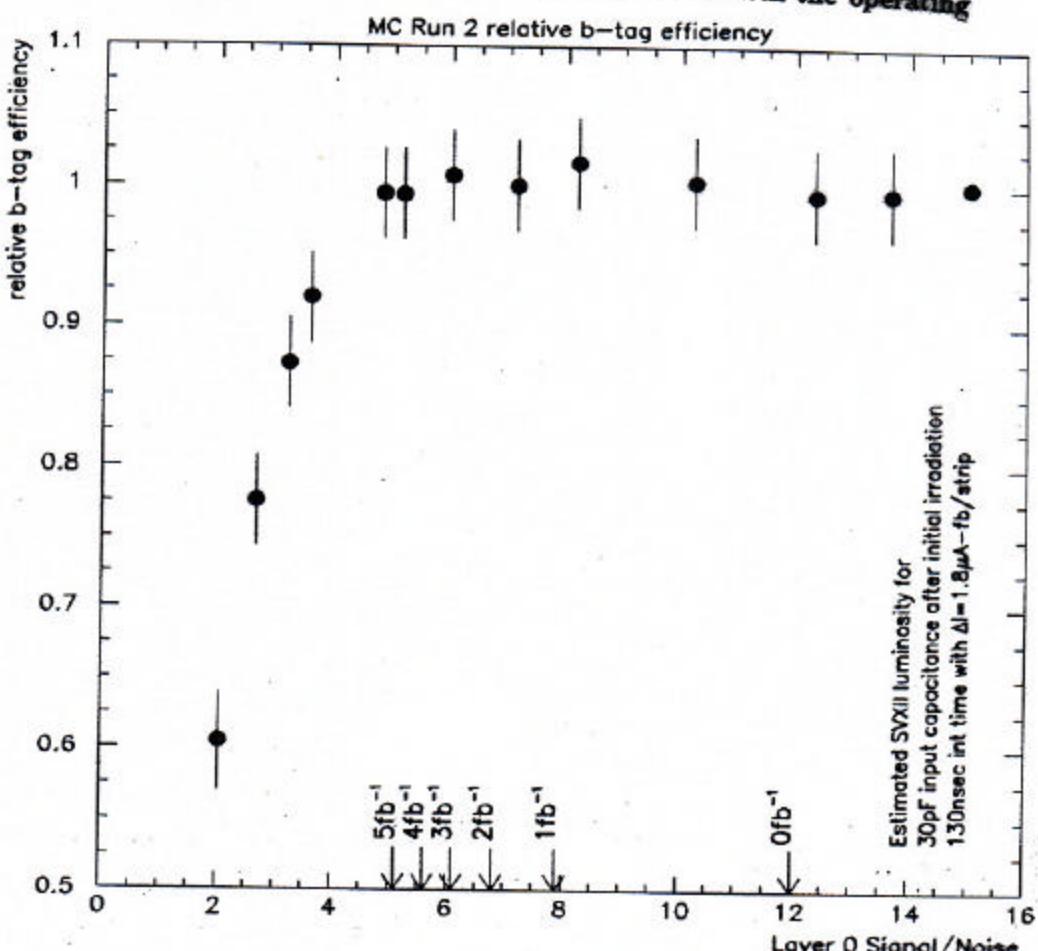


Figure 7: SVX' b tag efficiency versus SNR as determined with the new simulation. Corresponding integrated luminosities are shown along the bottom of the plot for the SVX II detector assuming only shot noise. The errors shown are statistical and correlated as discussed in the text.

Radiation concerns for Run IIa silicon

- Degradation of Signal/Noise
 1. Full signal collection may be difficult after high dose (depletion).
 2. Noise from increased leakage currents.
- Component Robustness
 1. Silicon sensors – a concern for L00, SVXII, and D0 90°
 2. Readout electronics (inner: SVX3 chip, hybrids) – possible concern for L00?
 3. Readout electronics (outer: port cards, DOIMs, etc) – next talk
 4. Single event upset – Not a problem with 0.8 μm process.

This talk will cover only recent estimates of depletion voltages and currents.

The oft-quoted numbers (from CDF3408) are a dose of 0.5 Mrad/fb⁻¹. This is based on leakage current measurements during Run 1a and is conservative. Is this still correct?

Leakage Current Estimates

For the innermost layer of SVX and SVX' ($r \approx 3.0$ cm) leakage vs strip was found to be

$$I^{SVX} = 0.80 \text{ nA/strip/pb}^{-1} \quad (1)$$

$$I^{SVX'} = 0.63 \text{ nA/strip/pb}^{-1} \quad (2)$$

at 24 ± 2 °C and with a radial dependence proportional to $r^{-1.68}$, where pb^{-1} refers to delivered luminosity [CDF3937].

From an average of the equations above and converting to $T = 15$ °C, $r = 2.54$ cm and strip volume to 2.79×10^{-3} cm³:

$$I_{L0}^{15^{\circ}C} = I_{3.0\text{cm}}^{24^{\circ}C} \left[\frac{2.79 \times 10^{-3} \text{ cm}^3}{4.59 \times 10^{-3} \text{ cm}^3} \right] \left[\frac{1}{2.265} \right] \left[\frac{2.54 \text{ cm}}{3.00 \text{ cm}} \right]^{-1.68} \quad (3)$$

$$= 0.25 \text{ nA/strip/pb}^{-1} \quad (4)$$

For L00 we use $T = 5$ °C, $r = 1.35$ cm and strip volume to 1.13×10^{-3} cm³:

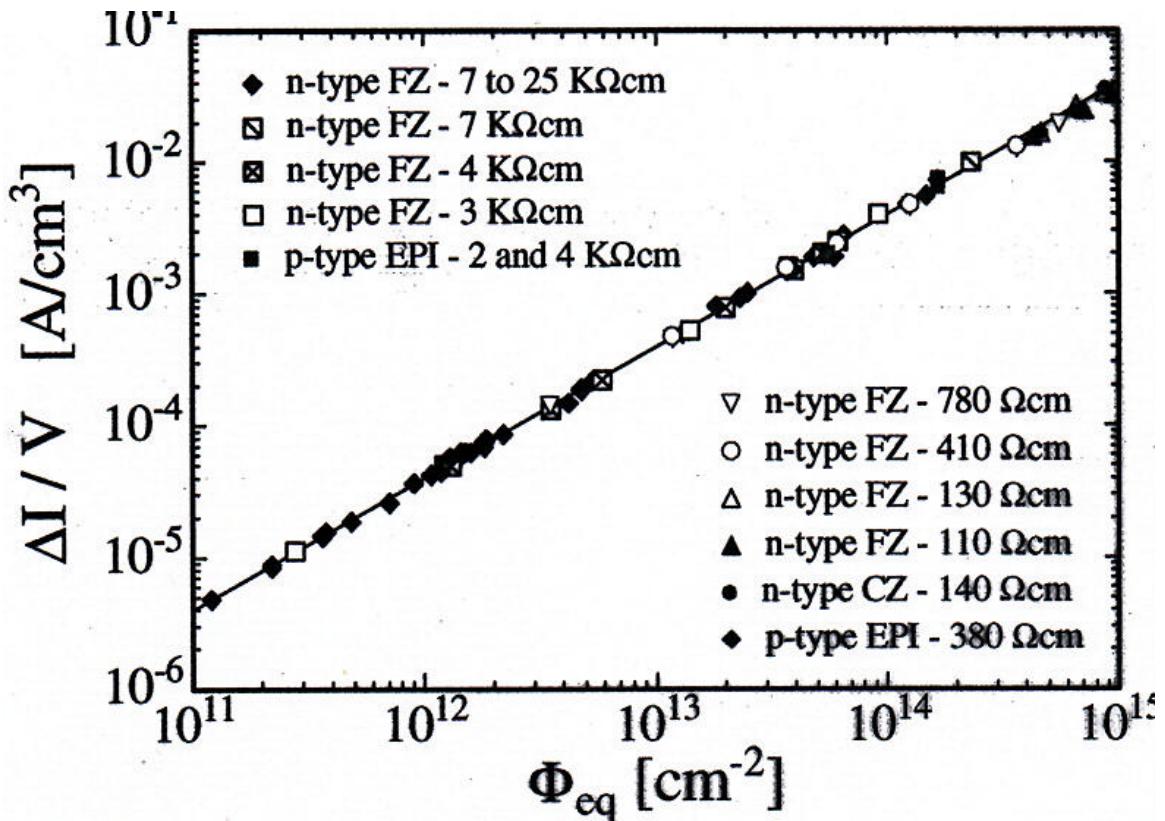
$$I_{L00}^{5^{\circ}C} = I_{3.0\text{cm}}^{24^{\circ}C} \left[\frac{1.13 \times 10^{-3} \text{ cm}^3}{4.59 \times 10^{-3} \text{ cm}^3} \right] \left[\frac{1}{5.963} \right] \left[\frac{1.35 \text{ cm}}{3.00 \text{ cm}} \right]^{-1.68} \quad (5)$$

$$= 0.11 \text{ nA/strip/pb}^{-1} \quad (6)$$

To find the fluence (in terms of 1 MeV neutron equivalent dose) we use the relation for current (at 20°C) and $I_{\text{strip}} = I_0 + \alpha \times \Phi \times \text{Vol}_{\text{strip}}$. Following CDF3937 we chose $\alpha_{\text{effective}} = 1.1 \times \alpha_{\infty} = 4.4 \times 10^{-17} \text{ A/cm}$.

$$\Phi_{L0}^{1\text{MeVn}} = \frac{(0.25 \times 1.58) \text{ nA/strip/pb}^{-1}}{\alpha_{\text{effective}} \cdot 2.79 \times 10^{-3} (\text{cm}^3/\text{strip})} \quad (7)$$

$$= 0.32 \times 10^{13} (1\text{MeVn})/\text{cm}^2/\text{fb}^{-1} \quad (8)$$



Is a good V_{dep} model really important?

- For L00, no
 1. Deterioration of charge collection efficiency should not cause problems at Tevatron fluences.
 2. Not a serious design or operational limitation.
- For SVXII, yes
 1. Double sided AC coupled silicon with 100V integrated capacitors; 200V max.
 2. Voltage drop across filter and biasing resistors should not be large.
 3. Microdischarge problems begin to occur above 170V.
- For D0 90°, yes
 1. Double sided AC coupled silicon with 100V integrated capacitors; 200V max.
 2. Moderate voltage drop, but higher voltage power supplies (so not a problem).
 3. Microdischarge problems with split biasing; 100V+30V

Comparison to previous estimates

- This compares very favorably with previous (design) estimates.

Using the average of Run Ia and Ib (the previous page):

$$\Phi_{L0} = 0.32 \times 10^{13} \text{ cm}^{-2}/\text{fb}^{-1} \quad (9)$$

Numbers from CDF3408 (the ones everyone remembers):

$$\Phi_{L0} = 0.75 \times 10^{13} \text{ cm}^{-2}/\text{fb}^{-1} \quad (10)$$

- Why the change?
 1. Best (rather than conservative) estimate.
 2. Larger damage constant α_∞ .

Depletion Voltage Prediction

The depletion voltage in a planar diode is given by

$$V_{\text{planar}} \propto d^2 \cdot |N_{\text{eff}}| \quad (11)$$

where N_{eff} is the effective doping concentration, and

$$\Delta N_{\text{eff}}(\Phi, t, T) \approx N_C(\Phi) + N_Y(\Phi, t, T). \quad (12)$$

This equation can be broken up into a stable defect portion and a reverse annealing portion as follows;

$$N_C(\Phi) = N_{C0}(1 - e^{-c\Phi}) + g_C \quad (13)$$

$$N_Y(\Phi, t, T) = N_{X0}(\Phi) \left(1 - \frac{1}{1 + N_{X0}(\Phi) k_0 e^{-E_a/k_B T t}}\right) \quad (14)$$

(for example A.Chilingarov *et al*, NIM A360 432-437). Now for strip sensors,

$$V_{\text{depletion}} = V_{\text{planar}} \left(1 + 2 \frac{p}{d} f(w/p)\right) \quad (15)$$

To predict the depletion voltage as a function of dose, we need to measure N_{C0} for Hamamatsu silicon.

Depletion Voltage Modeling (continued)

- Model includes both the short term beneficial annealing and the long term reverse annealing.
- Model also includes an estimate of the 'overvoltage' required (from NIM A 342 (1994) 90). This is typically a small effect.
- Damage constants used are listed in the table below. They are averages of several measurements compiled by Feick (in his dissertation).

| Parameter | Neutrons | Protons | Pions |
|---|-----------------|-------------------|-----------------|
| g_Y (10^{-2}cm^{-1}) | 4.6 ± 0.3 | 5.80 ± 0.3 | 8.1 ± 0.5 |
| g_C (10^{-2}cm^{-1}) | 1.77 ± 0.07 | 1.15 ± 0.09 | 2.01 ± 0.05 |
| N_{C0} (10^{11}cm^{-3}) | 2.0 | 6.3 | 3.9 |
| c (10^{-13}cm^2) | 2.29 ± 0.63 | 0.96 ± 0.19 | 1.64 ± 0.29 |
| E_a (eV) | | | 1.31 ± 0.04 |
| k_0 ($\text{cm}^3 \text{s}^{-1}$) | | 520 (128 to 2110) | |
| α_∞ (10^{-17}cm^2) | 2.86 ± 0.18 | 2.22 ± 0.10 | 3.89 ± 0.20 |

- g_Y , g_C , and N_{C0} – These parameters determine the variation of N_{eff} as a function of fluence (1 MeV neutron equivalent dose).
- c – the 'donar removal' constant
- E_a – activation energy
- k_0 – frequency factor
- α_∞ – reverse current normalized to the fluence

Parameters used the V_{dep} model

| Parameter | L00 | L0 | L1 | L2 | D90 |
|---------------------------|-----|-----|-------|----|-------|
| n width (μm) | 50 | 30 | 20 | 15 | 22 |
| n pitch (μm) | 50 | 141 | 125.5 | 60 | 153.5 |
| p width (μm) | 8 | 14 | 14 | 15 | 17 |
| p pitch (μm) | 25 | 60 | 62 | 60 | 50 |
| V_{dep} initial (V) | 70 | 65 | 65 | 25 | 30 |
| temperature (C) | 5 | 15 | 15 | 15 | 10 |

A scaling of the fluence is conducted ($r^{-1.68}$) in the plots below to account for the increased dose in the inner layers. The horizontal axis corresponds to 1.0×10^{13} particles (protons, pions) per cm^2 .

$$L00 = (2.54/1.35)^{1.68} = 2.75$$

$$L0 = (2.54/2.54)^{1.68} = 1.00$$

$$L1 = (2.54/4.12)^{1.68} = 0.44$$

$$L2 = (2.54/6.52)^{1.68} = 0.21$$

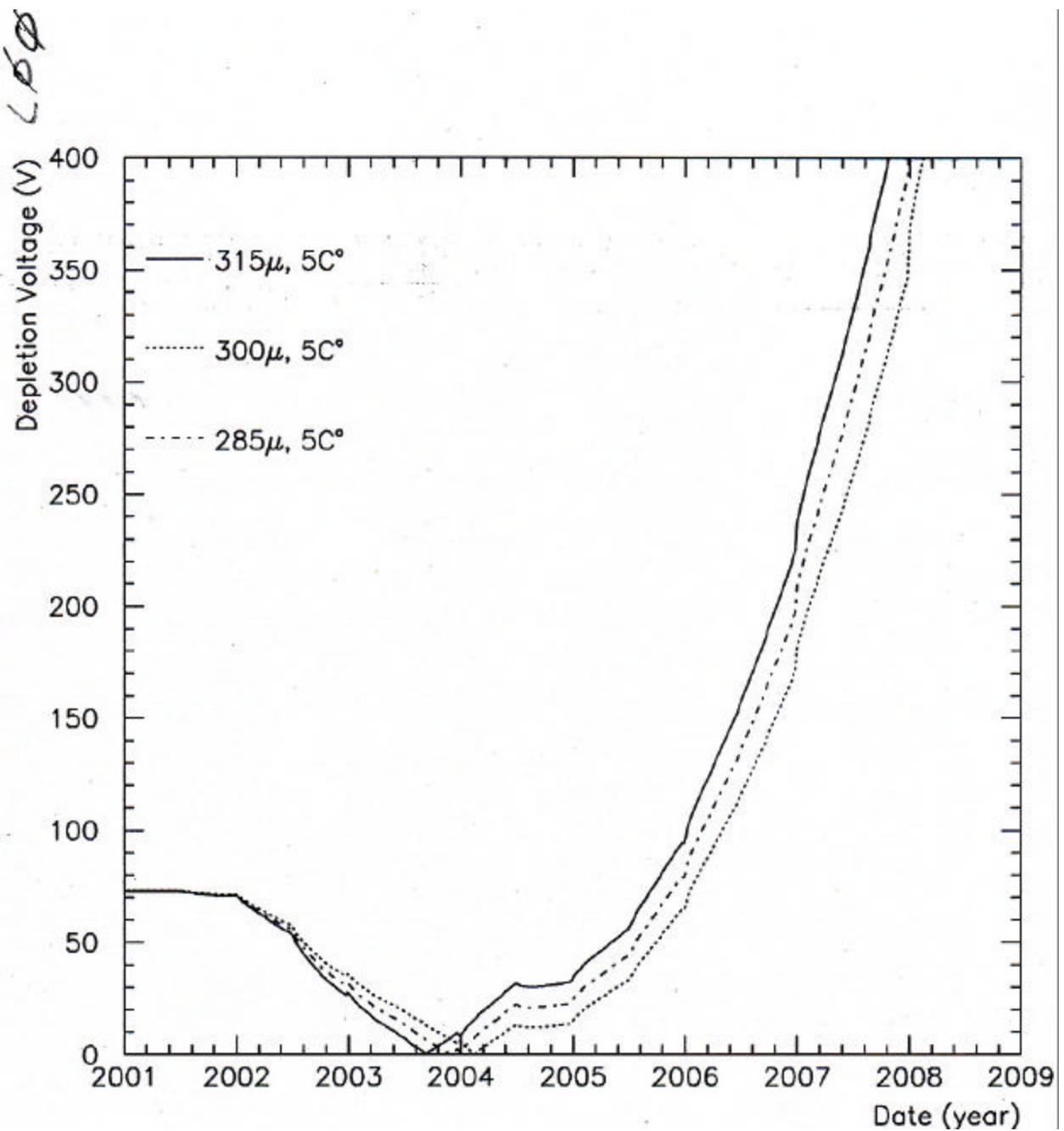
$$D90 = (2.54/2.70)^{1.68} = 0.90$$

Plots assume 1.0×10^{13} dose per year on L0, and the dose for other layers is scaled as shown above.

a more recent model...

| Year | days | Luminosity (fb ⁻¹ /yr) | int | Fluence x10 ¹² | L00 | SVX | SVX2 | ISL | IS |
|--------|------|--------------------------------------|------|------------------------------|-----|-----|------|-----|----|
| 2001 | 179 | 0.00 | | 0.00 | | | | | |
| 2001.5 | 126 | 0.01 | | 0.075 | 24 | 10 | 15 | 20 | |
| | 60 | | | 0.00 | 20 | 24 | 24 | 24 | |
| 2002 | 179 | 0.1 | | 0.75 | 5 | 10 | 15 | 20 | |
| 2002.5 | 179 | 0.3 | 0.4 | 2.25 | 5 | 10 | 15 | 20 | |
| | 7 | | | 0.00 | 20 | 24 | 24 | 24 | |
| 2003 | 179 | 0.4 | | 3.00 | 5 | 10 | 15 | 20 | |
| 2003.5 | 179 | 0.5 | 1.3 | 3.75 | 5 | 10 | 15 | 20 | |
| | 7 | | | 0.00 | 20 | 24 | 24 | 24 | |
| 2004 | 179 | 0.6 | 1.9 | 4.50 | 5 | 10 | 15 | 20 | |
| 2004.5 | 179 | | | 0.00 | 5 | 10 | 15 | 20 | 2 |
| | 7 | | | 0.00 | 20 | 24 | 24 | 24 | |
| 2005 | 179 | 0.5 | | 3.75 | 5 | 10 | 15 | 20 | |
| 2005.5 | 179 | 1.0 | 3.4 | 7.50 | 5 | 10 | 15 | 20 | |
| | 7 | | | 0.00 | 20 | 24 | 24 | 24 | |
| 2006 | 179 | 1.3 | | 9.75 | 5 | 10 | 15 | 20 | |
| 2006.5 | 179 | 1.5 | 6.2 | 11.25 | 5 | 10 | 15 | 20 | |
| | 7 | | | 0.00 | 20 | 24 | 24 | 24 | |
| 2007 | 179 | 1.7 | | 12.75 | 5 | 10 | 15 | 20 | |
| 2007.5 | 179 | 1.9 | 9.8 | 14.25 | 5 | 10 | 15 | 20 | |
| | 7 | | | 0.00 | 20 | 24 | 24 | 24 | |
| 2008 | 179 | 2.3 | | 17.25 | 5 | 10 | 15 | 20 | |
| 2008.5 | 179 | 2.3 | 14.4 | 17.25 | 5 | 10 | 15 | 20 | |

Flux(SVXII L0, proton) = 0.75e13 n/cm⁻²/fb⁻¹ (same as runIIb model). The model for lum is basically still the old one, but shifted by a 1.5 years (Merriner's PAC talk of June 20, 2000). Fluence scaling by radius... same as before ($r^{-1.7}$).



L60

